

IMMOBILIZATION OF OLIGONUCLEOTIDES AND PROTEINS
IN SUGAR-CONTAINING HYDROGELS

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Background of the Invention

Field and Background of the Invention

Immobilization of deoxyribonucleic acid (DNA), ribonucleic acid (RNA), proteins,
10 antigens, and other biomolecules on a variety of solid substrates, typically glass, provides
the basis for array-based bioassays. Examples of such technologies include patterning of
DNA probes in hybridization assays for clinical diagnostics, drug discovery, and
pathogen detection and arraying proteins and antigens for antibody detection. A number
of strategies have been developed for the attachment of oligomers to glass substrates.
15 Single-stranded DNA (ssDNA) probes are commonly synthesized on surfaces
photolithographically, Pease et al, *Proc. Natl. Acad. Sci. U.S.A.* **1994**, 91, 5022-5026,
electrostatically adsorbed to the substrate, Schena et al, *Science* **1995**, 270, 467-470 or
covalently attached to a self-assembled monolayer, Chrisey et al, *Nucleic Acid Res.* **1996**,
24, 3031-3039, Zammattéo et al, *Anal Biochem.* **2000**, 280, 143-150,
20 A major limitation for the use of microarrays in pathogen detection is the low signal
levels observed when probe DNA is confined to the substrate surface. An alternative is
immobilizing ssDNA in a three-dimensional hydrogel allowing for higher density and
sensitivity, Timofeev et al, *Nucleic Acid Res.* **1996**, 24, 3142-3149. U. S. Patent No.
5,981,734 describes a method for immobilizing biomolecules such as oligonucleotides in
25 polyacrylamide gels, either through copolymerization of allyl-substituted
oligonucleotides or incorporation of functional groups which can be covalently coupled
to modified oligonucleotides. U. S. Patent No. 6,180,770 describes a method for
preparing oligonucleotides derivatized with a terminal polymerizable acrylamide. These
monomers can then be copolymerized into an acrylamide hydrogel to produce a
30 polymerized layer containing the covalently linked ssDNA molecule. This technology
has been licensed to Apogent Discoveries and is commercially available.

Conventional hydrogels suffer from a number of limitations. In general, it is difficult
to obtain water contents greater than 95 wt%. This results in a small mesh size in the gel,

limiting the diffusion of large macromolecules or particles. For example, target ssDNA with length greater than 200 nucleotides are unable to permeate into a standard 5% polyacrylamide gel, Guschin et al, *Anal. Biochem.* **1997**, 250,203-211. The networks are often heterogeneous and the monomers can be toxic (e.g. acrylamide). The polymeric hydrogels described in this Disclosure, for example those based on monomeric sugar acrylates or methacrylates, do not experience the drawbacks outlined above. Enzymatic acryloylation provides a simple method for forming the monomers with high regioselectivity, Martin et al, *Macromolecules*, **1992**, 25, 7081-7085. These hydrogels have equilibrium water contents above 95% resulting in pore sizes of 500 nm or larger, Martin et al, *Biomaterials*, **1998**, 19, 69-76. U. S. Patent No. 5,854,030 provides the methodology for the chemoenzymatic synthesis of the monomers and subsequent formation of the hydrogels. The above cited references, including publications and patents are incorporated herein by reference in their entirety.

Summary of the Invention

This invention details the synthesis of polymeric sugar-containing hydrogels and their use as three-dimensional, highly macroporous substrates for the immobilization of oligonucleotides, peptides, proteins, and other biomolecules. These hydrogels are formed from compounds containing polymerizable double bonds. Examples of such compounds include, but are not limited to, acrylates, methacrylates, acrylamides and methacrylamides. The sugar compounds may be hexose, pentose, tetrose, or triose, or monosaccharide, di-, tri-, tetra-, penta-, hexa-, hepta-, octa-, nona-, or decasaccharides. If glycosides are used, they may contain either alpha or beta aglycon linkages. The hydrogel provides a support with activated functional groups for biomolecule attachment throughout the matrix. The high porosity of the sugar-containing hydrogels allows for rapid diffusion of large (up to two micron diameter) molecules or particles. This includes long DNA sequences (e.g. greater than 100,000 nucleotide bases) and large antibodies, functionalized microbeads as well as semiconductor and metal nanoparticles currently being explored as alternatives to conventional fluorophores for ultrasensitive optical detection. A further advantage of the hydrogel matrix is its extremely low nonspecific absorption of labeled biomolecular targets, and the large number of reactive sites available for molecular attachment. The high density of immobilized probes throughout

the volume of the gel leads to a greater detection sensitivity versus a similarly derivatized flat solid substrate.

Three methods for incorporating biomolecules into the sugar-containing hydrogels are disclosed. All methods result in covalent linkage of the biomolecules to the three-
5 dimensional gel matrix. In the first case, oligonucleotides with a terminal acrydine unit are polymerized with a sugar compound having a polymerizable double bond such as a sugar acrylate or sugar methacrylate monomer and a crosslinker having at least two polymerizable double bonds, providing a direct covalent link to the acrylate backbone.

In the second case, a sugar compound having a polymerizable double bond such as a
10 sugar acrylate or sugar methacrylate monomer is polymerized with a crosslinker having at least two polymerizable double bonds and a third compound having a polymerizable double bond and a group selected to allow covalent attachment of oligonucleotides, peptides, proteins, or other biomolecules. The crosslinker and the third compound may contain an acrylate, methacrylate, acrylamide, or methacrylamide moiety. In one
15 instance, amino groups are introduced into the gel by using N- (3- aminopropyl) methacrylamide as a monomer. A number of strategies are then available for the attachment of biomolecule amino groups to the gel polymer. Aldehyde terminated oligonucleotides, peptides, proteins, or other biomolecules react with the amine in the presence of a reducing agent, forming a covalent bond. Phosphorylated or carboxylated
20 oligonucleotides, peptides, proteins, or other biomolecules can be covalently attached to the amino group using carbodiimide condensation mediated by a compound such as EDC. Amino terminated oligonucleotides, peptides, proteins, or other biomolecules can be coupled using a homobifunctional crosslinker such as diisothiocyanate or bis(sulfosuccinimidyl) suberate (BS³). In the third instance, carboxyl groups are
25 introduced into the gel by introducing N- (3- carboxylpropyl) methacrylamide as a monomer. Amino terminated oligonucleotides can be covalently attached to the carboxyl group through carbodiimide condensation. In a final instance, aldehyde groups are introduced into the gel by using N-(5,6-di-*O*-isopropylidene) hexylacrylamide as a monomer. Aldehydes can then be generated by removing the isopropylidene
30 protecting groups using acetic acid (Timofeev et al, 1996). Aminated oligonucleotides, peptides, proteins, or other biomolecules can then be reacted with the aldehyde groups,

forming covalent linkages. The gels described in this Invention have water contents of at least 90 wt%, and in preferred embodiments have water contents of 94 wt% of greater.

Figures

Figure 1. shows one possible generalized chemical structure of the polymer network component of the sugar-containing hydrogels of this invention. In the preferred
5 embodiments, R_1 is H, alkyl or phenyl, R_2 - R_7 are H, OH, O-phenyl, or O-methyl, R_8 is H or methyl, R_9 is OH, propane 1,3 diamine, or aminohydroxy acetic acid, and R_{10} is H or methyl. R_9 can also be a biomolecule covalently attached via an amine linkage. In this
10 Figure the repeat units m, n, and p are residues originating from acrylate, methacrylate, acrylamide, or methacrylamide monomers.

Figure 2 shows the chemical structures of several carbon-carbon double-bond containing bis-crosslinkers that could be used to form the polymer network.

Figure 3 shows the structure of two crosslinkers used to attach DNA, peptides, proteins, or other biomolecules via amine linkages -- BS³ (top) and EDC (bottom).

15 Figure 4. is a reaction diagram showing an EDC-mediated activation of a carboxylate moiety in the gel polymer network, and further reaction of the activated moiety with an amino group of an oligonucleotide, peptide, protein, or other biomolecule resulting in covalent attachment of the latter.

20 Figure 5. demonstrates that there is very little non-specific bonding of target molecules to the sugar hydrogels of this invention.

Figure 6. describes the time-dependent movement of fluorescent 2-micron diameter beads through an unmodified sugar poly(acrylate) hydrogel. Open circles, experimental data; filled circles, diffusion theory.

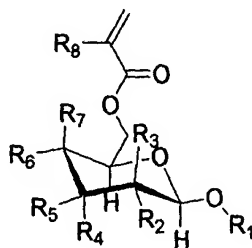
25 Figure 7. shows a micro array formed using the reaction an amino terminated DNA labeled in the 5' end with a fluorophore (Cy3) with an activated amino sugar hydrogel of the invention on a support.

Figure 8. shows a micro array of the DNA of Figure 4 after reaction with a carboxylate-modified sugar hydrogel on a support.

30 Figure 9. shows a micro array of a fluorophore labeled protein coupled to a carboxylate modified sugar hydrogel on a support.

Experimental Results

The galactose acrylate monomer, 6-acryloyl- β -O-methyl galactopyranoside (1) where R_1 is CH₃ was chemoenzymatically prepared using the procedure of Martin et al, 1992. The lipase from *Pseudomonas cepacia* catalyses the regioselective acryloylation at the 6-hydroxyl moiety of β -O-methyl galactopyranoside in anhydrous pyridine to give the monoacrylate. The acrylate (1) exists as α and β anomers and either or both may be used to create the sugar hydrogels of this invention.



In structure (1) and all sugar acrylates or sugar methacrylates used in this invention, R_1 is preferably a methyl group, R_2 - R_7 are preferably H or OH. For sugar acrylate, R_8 is H; for sugar methacrylate, R_8 is methyl. However, R_1 may also be without limitation, H, alkyl, aromatic, carbohydrate, and acryl and acrylamido. R_2 - R_7 may be in addition to H, or OH, isopropyl, alkyl, aromatic. It should be understood that other groups may be selected for R_1 , R_2 , and R_7 without deviating from the bounds of this invention. The sugar compounds (1) of this invention may be mono, di, or polysaccharides.

One possible generalized polymeric structure of the gel described in this invention is shown in Figure 1. In this the sugar acrylate or methacrylate (1) of choice is polymerized with a multifunctional bis-crosslinker having at least two polymerizable double bonds and a third compound having a polymerizable double bond and an amine, carboxyl or other group capable of forming covalent bonds with oligonucleotides and/or proteins. The crosslinking compounds are selected from bis-acrylamides, bis-acrylates and bis-vinyl compounds (Figure 2). The third compound is selected so that when the sugar hydrogel

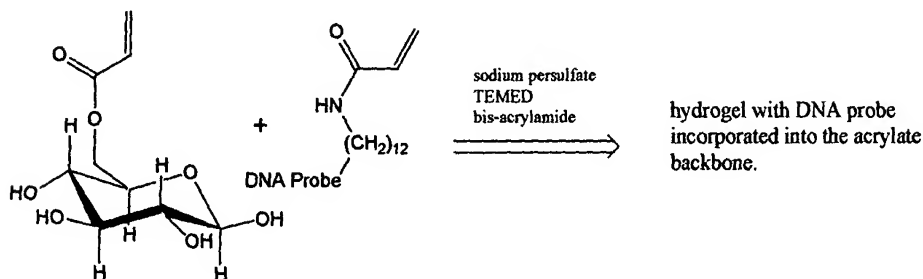
polymer is formed, the amino or carboxyl groups of the third compound provide reactive sites on the polymer backbone for reaction with coupling agents (Figure 3) that allow covalent attachment of oligonucleotides and proteins and other biomolecules of interest. Covalent bonding of the polymer reactive sites with compounds of interest provides the basis of assay for the target molecules of interest.

Copolymerization of Acrydine DNA with Sugar Acrylate

Oligonucleotides containing an acrylic acid group directly attached to their 5'-end were purchased from Integrated DNA Technologies. Samples were prepared on glass slides that had been functionalized with methacrylate groups using the following procedure. The glass slide is cleaned by immersion in a hydrochloric acid/methanol mixture, followed by sulfuric acid and treated with a 4% (v/v) solution of methacryloxypropyl trimethoxysilane (MTPTS) (93 mL methanol, 2.7 mL water, 0.3 mL glacial acetic acid, 4 mL of silane) at 60 °C for 1 hour. The slides are then rinsed in methanol, water, and methanol again. The slides are baked for 5 minutes at 120 °C.

Slides can be stored in a dessicator for a period of a few weeks with no loss of activity.

The galactose acrylate (1) was dissolved in deionized water at a concentration of 20-40% (w/v), along with the cross-linker N,N'-Methylene-bis-acrylamide at 3-4% (w/w) of the monomer concentration and the acrydine DNA at a concentration of 0.1-1 mole% of the bis-acrylamide concentration. This procedure uses a few nmoles of DNA for a 1 mL synthesis. The polymerization is accomplished via a free radical polymerization, common for formation of poly(acrylamide) gel matrixes. N,N,N',N'-tetramethyl ethylenediamine (TEMED) and sodium persulfate are used to initiate polymerization. This scheme is depicted below.



We have applied this technique to oligonucleotides containing 20 bases with an acrylate group on the 5' end and a fluorophore (Cy3) on the 3' end. Figure 2. shows the fluorescence intensity of the immobilized DNA (circles). The intensity does not change with repeated washings indicating the DNA is covalently immobilized. On the other
5 hand, when non-acrylated DNA is used (squares), the fluorescent intensity decreases to the background level (diamonds) after two washes. This shows that there is extremely low non-specific absorption of target molecules to the sugar acrylate gel. This provides the low background levels necessary for ultrasensitive detection.

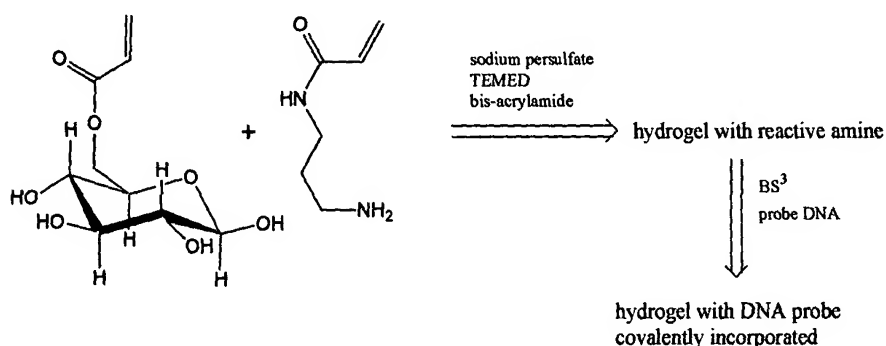
Formation of Amino-modified Sugar Acrylate Hydrogel

10 Thin hydrogels (~100 micron thickness) were formed on glass slides that had been functionalized with acrylic groups through the procedure above. The galactose acrylate (1) was dissolved in deionized water at a concentration of 20-40% (w/v), along with N, N methylene bis-acrylamide cross-linker at 3-4% (w/w) of the monomer concentration and *N*-(3-aminopropyl) methacrylamide 4-5% (w/w) of the sugar acrylate monomer
15 concentration. The polymerization is accomplished via a free radical polymerization using the initiators TEMED and sodium persulfate.

In order to study the porosity of the sugar acrylate gel, we measured the passive diffusion of fluorescently labeled beads through a non-modified sugar acrylate hydrogel. Figure 3. shows the diffusion of FITC-labeled 2 micron diameter polystyrene beads
20 through poly(6-acryloyl- β -O-methyl galactopyranoside) hydrogel swollen in 0.25 M PBS. The gel had a 94 wt% aqueous solution content. The curve fit indicates that at $t = \infty$, ~384,000 beads will have passed through the gel into the receiving chamber. When the experiment was done with no gel in place, at equilibrium ~2,110,000 beads had entered the receiving chamber. Thus, 3.84/21.1 or ~18% of the beads that enter the gel
25 actually pass completely through it, and the remaining 82% become trapped, indicating that the large pores are interconnected, and allow significant diffusion of the 2 micron spheres through the gel volume. The gels can be formulated to have a pore size ranging from 0.1 microns in diameter to 0.6 microns in diameter using the original synthesis conditions described previously (Martin, 1998), and by using the synthesis conditions
30 described herein, pore sizes of significantly greater than 2 microns in diameter can clearly be achieved.

Linking of Oligonucleotides to Amino Sugar Gel

The amino moieties that have been linked into the gel are activated for attachment to an aminated oligonucleotides segment using a water soluble homobifunctional crosslinker bis(sulfosuccinimidyl) suberate (BS³) which contains a reactive n-
5 hydroxysuccinimide ester (NHS-ester). The crosslinker is added to the gel under acidic conditions (10 mM sodium phosphate, pH 6.0) at a concentration of 2.5 mM BS³ and allowed to react for 1 hour to form a stable covalent amide bond. This creates an amine reactive group on the backbone of the gel. The entire scheme is depicted below.



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The amino terminated DNA is then added spot-wise to the activated gel using a BioChip non-contact microdispensing system. The microarrayer prints an array of oligonucleotides (900 pL per spot) resulting in a spot diameter of 300 μm and an
15 interelement distance of 500 μm. The concentration of oligonucleotide was from 6.25 μM to 100 μM. The DNA is allowed to react with the activated substrate for 12 hours. The gel is then rinsed three times with a 4X saline sodium citrate buffer solution (0.60 M NaCl, 60 mM sodium citrate) to remove unattached DNA segments. We have applied this technique to oligonucleotides containing 24 bases with an amino group on the 3' end
20 and a fluorophore (Cy3) on the 5' end. The resulting array can then be visualized using a conventional fluorescent array reader. Figure 4 below shows a photograph of a 10 x 5 array created in this manner, where the rows are a serial dilution of the DNA. Each row contains a replicate of ten spots, with a dilution by 2 between rows (top row = 100 μM, second row = 50 μM, third row = 25 μM, fourth row = 12.5 μM, bottom row = 6.25 μM).
25 Note that these arrays appear approximately one-hundred times brighter relative to the

same concentration spotted onto a flat, aminosilane substrate using the same crosslinking procedure.

Formation of Carboxylate-modified Sugar Acrylate Hydrogel

5 Thin hydrogels (~100 micron thickness) were formed on glass slides that had been functionalized with acrylate groups through the procedure above. The galactose acrylate (1) was dissolved in deionized water at a concentration of 20-40% (w/v), along with the cross-linker N,N'-Methylene-bis-acrylamide at 3-4% (w/w) of the monomer concentration and 2-acrylamidohydroxyacetic acid 4-5% (w/w) of the sugar acrylate
10 monomer concentration. The polymerization procedure is the same as for the amino-modified hydrogel.

Linking of Oligonucleotides to Carboxy Sugar Gel

Five μ moles of 1-ethyl-3-(3-dimethylaminopropyl) carbodiimide-HCL (EDC) are added to the amino terminated oligonucleotide solution at pH 7.2-7.4. The DNA/EDC
15 solution is then added spot-wise to the gel using a non-contact microdispensing system. The DNA is allowed to react with the gel matrix for 12 hours at room temperature. The gel is then rinsed three times with 4X saline sodium citrate buffer solution to remove unattached DNA segments. We have applied this technique to the same amino modified oligonucleotides described above. We arrayed these oligos on a carboxylate-modified gel
20 in a serial dilution starting at 25 μ M. Figure 5 indicates that immobilization of the DNA is occurring, but the fluorescent intensity is lower than observed using the BS³ crosslinker. Note that in this case we are starting at 1/4 the density, so the top row here should be compared to the third row above.

Linking of Proteins to Amino Sugar Gel

25 An amino functionalized sugar acrylate was activated with BS³ using the procedure described above. The protein, Staphylococcal enterotoxin B (SEB), prepared in 10 mM sodium phosphate, pH 7.4 reacts with the NHS-ester gel support. Reaction of the ester with the lysine moiety of the protein provides the final amide linkage to the gel substrate.

Linking of Proteins to Carboxy Sugar Gel

30 A carboxy-functionalized sugar acrylate was activated using carbodiimide chemistry as described above. The protein, Cy3-labeled Staphylococcal enterotoxin B (SEB), prepared in 10 mM sodium phosphate, pH 7.4 was allowed to react with the carboxylic

acid moiety in the presence of EDC. Reaction of the carboxylic acid group with the primary amines of the protein provided a stable covalent amide linkage between the protein and the gel substrate. The SEB solution (concentration range 0.1 $\mu\text{g/mL}$ to 200 $\mu\text{g/mL}$) was deposited in replicates of 15 onto the modified gel using the BioChip
5 microarrayer. Each printed element had 300 μm spot diameter, 900 pL print volume, and 500 μm inter-element distance. The protein modified gel slides were rinsed briefly with PBS, pH 7.4, H_2O , air dried and subsequently stored at 4 $^{\circ}\text{C}$. Figure 6. shown below indicates that we are getting significant immobilization of the Cy5-labeled SEB with the carboxylated sugar acrylate gel.

- 10 Methods for assaying biomolecules of interest include well known optical, fluorescence, and radioactivity means and the like, depending on specific molecules selected for assay.